CONTROL SYSTEM OF THE SUPERCONDUCTING MAGNET TEST BENCH FOR THE NICA ACCELERATOR COMPLEX

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The control system of the superconducting magnet cryogenic test bench is designed in Tango Controls format. It includes: a thermometry system and satellite refrigerators control system. The report describes hardware, software modules for data acquisition and management, an archiving system, configuration system, access control system, web service and web client applications.

Keywords: NICA, JINR, Tango, Tango Controls, control system, thermometry, resistance temperature sensors, TVO, Pt100, Cernox, satellite refrigerator, OPC DA, superconducting magnet, web, web clients, REST, API, access control, HDB++

1. Superconducting magnet cryogenic test bench.

Superconducting (SC) magnets for the NICA accelerator complex [1] are being manufactured in Dubna. To perform vacuum, cryogenic and magnetic tests of these magnets, a superconducting magnet cryogenic test bench is being developed at LHEP JINR. It consists of 3 helium satellite refrigerators, 6 feed boxes with 12 high-temperature superconductivity (HTS) current leads of 18 kA pulse operation, a system for "cold" (at the temperature of liquid helium) magnetic measurements, vacuum and control systems [2]. It is intended to provide cold tests of SC magnets simultaneously at 6 experimental shoulders and is used for testing NICA (booster, collider) and FAIR [3] (SIS100 synchrotron) SC magnets. The schematic view of the facility hall is shown in figure 1. The general view of the cryogenic test bench is shown in figure 2.

Figure 1. Schematic 3d-view of the facility halls and main equipment placement: 1 – Nuclotron-type SC cable production hall; 2 – magnet winding production hall; 3 – assembling the yoke of the magnet and winding, welding and brazing cooling channels of magnets; 4 – room temperature magnetic measurements; 5 – checking vacuum tightness of cooling channels, beam pipes and cryostats; 6 – assembling magnets in cryostats; 7 – cryogenic tests of magnets at 6 benches; 8 – power converters hall

Figure 2. SC magnets cryogenic test bench: 1-helium satellite refrigerator; 2 – feed box with HTS current leads; 3 – vacuum system; 4 – cryostat with SC magnet; 18 kA bus bar

2. Control system

The purpose of the control system is to control the satellite refrigerators and to provide measurements of temperature, pressure flows in various part of the experimental facility during the cryogenic tests. The system should be easily configurable, provide a convenient operator interface. It should have data archiving and access control systems. It should operate in 24*7*365*5 mode.

The SC magnet cryogenic test bench control system is based on Tango Controls [4]. It is a free, open source, object-oriented software toolkit, intended to build control systems. It allows one to develop cross-platform, fast, scalable and distributed solutions.

HDB++ [5] is a native Tango data archiving toolset. HDB++ uses Tango events to retrieve the data for storage. It allows optimizing the required storage capacity.

A custom server-side role-based Tango access control system [6] is used for logging and access rights management.

Single-page client web applications are used to create the operator interface. Sencha ExtJS framework [7] allows developing powerful, well-looking, flexible and convenient web applications. A RestDS Tango device-server [8] is used to provide access to the Tango modules via http(s) requests. It implements native Tango REST API [9].

3. Helium satellite refrigerator control system

The satellite refrigerators are intended to supply liquid helium and liquid nitrogen fluxes to the superconducting magnets windings. The control system regulates valves and monitors temperatures, pressures, gas flows and level values in various parts of a satellite refrigerator. The refrigerators were built at the Institute of Air Handling and Refrigeration [10] (ILK) in Dresden, Germany. Each satellite refrigerator is managed by an OMRON programmable logic (PLC) controller. To interact with PLC, an Open Platform Communications Data Access (OPC DA) server is used.

The control system includes:

- OMRON OPC DA servers;
- Tango OPCDA modules;
- Tango data archiving/extracting system;
- Custom Tango access control system;
- Tango WEB API service;
- Web client application;

The client application is developed as a web-desktop. It has highly flexible design and is very convenient for operators. It allows one to open and close the refrigerator valves and to look after the temperatures, pressures and gas levels. The values can be browsed as a mnemonic diagram, table and live-charts. The target refrigerator is determined by the hyperlink address. The system is self-configuring and does not require additional plugins to be installed. You only need a modern web browser and hyperlink address. Screenshots of the client application are shown in figure 3.

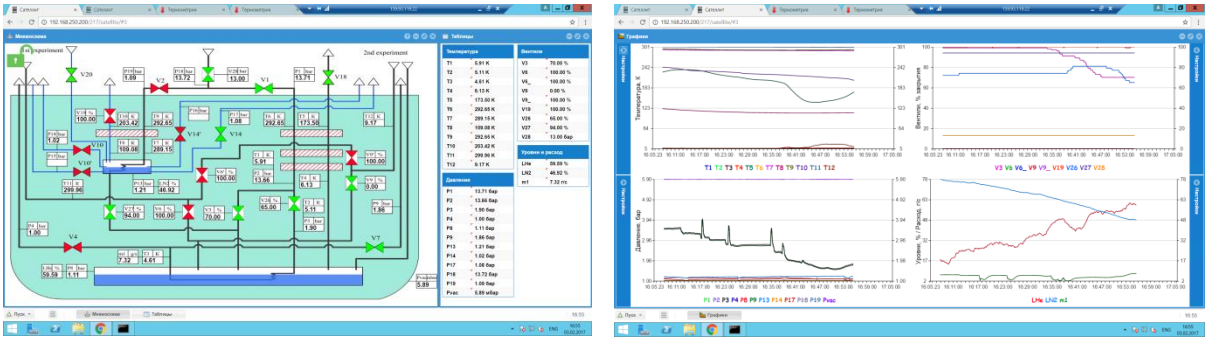

Figure 3. Screenshots of the satellite refrigerator control system web client application

4. Thermometry system

The thermometry system is intended to precise temperature control in parts of the test bench during cryogenic tests. Resistance temperature sensors are used as thermometers. The quantity of sensors, their location and characteristics depend on a type of the test session.

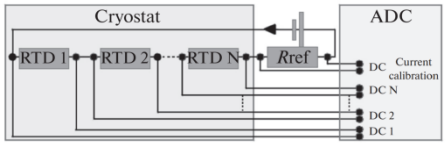

Figure 4. Thermometry system hardware general scheme

Three types of resistance temperature detectors are used in the thermometry system. Pt100 sensors with a range from 100Ω at a room temperature to 7Ω at 4K are used for temperature measurements in a range from 77K to 300K on the superconducting current leads. TVO sensors with a range from 1kΩ at a room temperature to 4.5kΩ at 4K are used for temperature measurements in a range from 4K to 300K in various parts of the thermostat and the examined magnet. Cernox sensors with a range from 100Ω at a room temperature to 100kΩ at 4K are used for temperature measurements in SIS100 SC magnets. The general scheme of the thermometry system is shown in figure 4. The sensors of each type are connected in series, and powered by reference current sources – 10μA for TVO and 500μA for Pt100 sensors. Each sensor is connected via a twisted pair to the differential input of the

data acquisition module to measure the voltage drop. It allows us to eliminate crosstalk. The sensor resistance is calculated using a reference current value. To take the deviation of current from the nominal value into account, precise current values are continuously measured through the voltage drop on the separate reference resistors. The temperature dependence on the resistance in a range 0-300K is approximated by a 6 degree polynomial for TVO sensors and 5 degree polynomial for PT100 sensors.

The data acquisition system hardware consists of 3 PXI Express chassis and several modules by National Instruments: NI PXI-8820 system controllers and NI PXIe-4357 data acquisition modules for RTD measurements (24 bit, 20 channels). The advantages of these modules are: high precision and high level of interference suppression at 50 Hz. It is very important because of a large amount of high power equipment in the test bench.

The data acquisition from the Cernox sensors is done by means of ILK monitors controlled via a Modbus protocol.

The thermometry system software includes:

- Configuration database (MySQL);
- Tango drivers for National Instruments data acquisition modules;
- Tango drivers for Modbus connection;
- Tango modules for data acquisition and temperature calculation;
- Tango data archiving/extracting system;
- Custom Tango access control system;
- Tango WEB API service;
- Web client application;

The measuring channels for various types of experiment session are configured by means of the custom configuration database.

The client application is also developed as a web desktop. It has very flexible design and allows data to be browsed as mnemonic diagrams, tables, live-charts and historical charts. Screenshots of the client application are shown in figure 5.

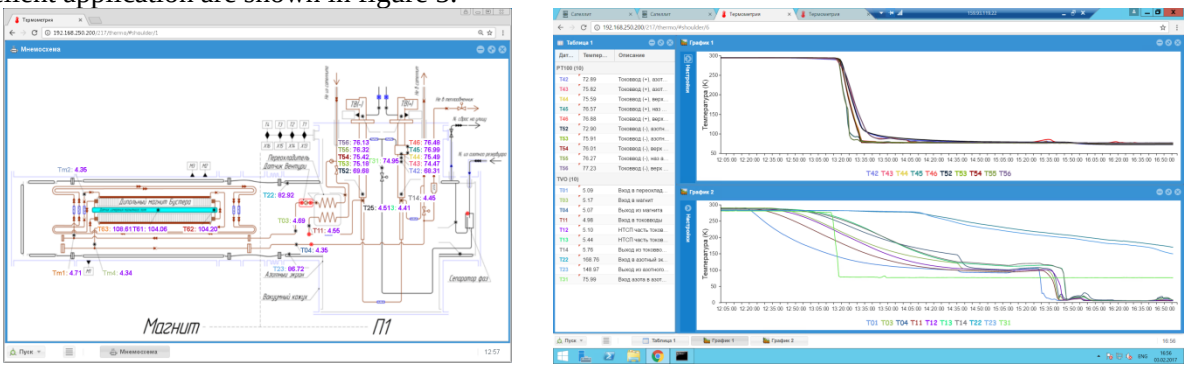

Figure 5. Screenshots of the thermometry system web client application

5. Control panel

Figure 6. Control panel

Figure 7. Dashboard

The main operator panel is shown in figure 6. It displays data from all satellite refrigerators and experimental shoulders. Web client applications are very suitable to layout the data across the multi-screen control panel. You only need to have several browser tabs with different hyperlinks. The actual information of the experiment is browsed in colorful dashboard. It is shown in figure 7. The dashboard is controlled by a NI LabView application and uses Tango WEB API to read data from the control system.

6. Conclusion

- The equipment developed by National Instruments, LakeShore and OMRON provides reliable operation;
- The Tango framework allows us to create a fast and scalable control system for the superconducting magnet cryogenic test bench;
- The Tango hardware drivers and data processing modules were tested during the operation in the round-the-clock mode;
- The Sencha ExtJS framework and Tango WEB API helps us to create flexible, nice and convenient web-client applications;
- The custom server-side role-based Tango access control system provides reliable access restriction;
- The native Tango data archiving system HDB++ simplifies long-time support of the data storage system;
- All the elements in the control system are operational prototypes for the control system of the NICA accelerator complex.

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